DOCUMENT RESUME

ED 240 704 EA 016 470

AUTHOR Peelle, Howard A.
TITLE Computer Metaphors: Approaches to Computer Literacy for Educators.
INSTITUTION International Council for Computers in Education, Eugene, Oreg.
PUB DATE 84
NOTE 49p.
AVAILABLE FROM Publications, International Council for Computers in Education, 1787 Agate Street, University of Oregon, Eugene, OR 97403 ($6.00 prepaid; quantity discounts; on non-prepaid orders, add $2.50 postage and handling).
PUB TYPE Viewpoints (120) -- Guides - Non-Classroom Use (055)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Computer Assisted Instruction; *Computer Literacy; *Computers; Educational Technology; Elementary Secondary Education; *Instructional Improvement; *Metaphors

ABSTRACT

Because metaphors offer ready perspectives for comprehending something new, this document examines various metaphors educators might use to help students develop computer literacy. Metaphors described are the computer as person (a complex system worthy of respect), tool (perhaps the most powerful and versatile known to humankind), brain (both brain and computer being excellent control devices), map (showing the locations and connections between various centers of knowledge), glass box (intended to reveal rather than conceal), vitamin (providing some essential vitamins for the educational diet), palette (for the creative artist), mentor (having some of the qualities of a good teacher), and catalyst (for revitalizing education). Among other computer literacy metaphors briefly noted are the computer as hydraulic system, pupil, toy, and idol. The document concludes that educators must think about how to go beyond metaphor to a more substantial understanding of computer science, information theory, and applications of advanced technology. (PB)

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COMPUTER METAPHORS: APPROACHES TO COMPUTER LITERACY FOR EDUCATORS

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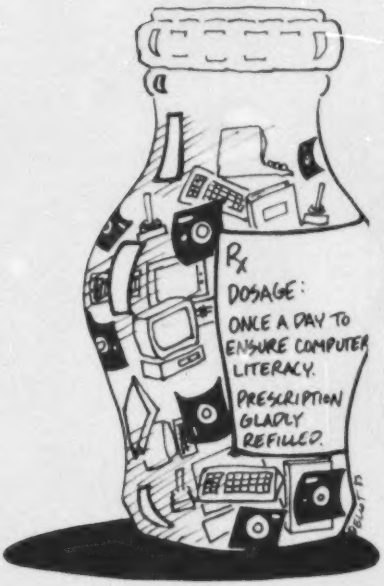

EA 016 470

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ICCE Publications

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This booklet is published by the International Council for Computers in Education, a non-profit, tax-exempt professional organization. ICCE is dedicated to improving educational uses of computers and to helping both students and teachers become more computer literate. ICCE publishes *The Computing Teacher*, a journal for teachers and for teachers of teachers. It also publishes over ten booklets of interest to educators.

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Illustrations by Jan Eliot

© ICCE 1984
(First Printing, January 1984)

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4

INTRODUCTION

Metaphors cultivate the mind. They prepare furrows for planting ideas, which in time grow to mature understanding. If the climate is too arid for learning or if work has been neglected for too long, metaphors can break through an unreceptive crust to more fertile ground where the nutrients of teaching can be absorbed.

Educators have used metaphor productively for centuries, just as farmers have utilized the plow. Myths, imagery and figurative language served to cut between the known and the unknown. For instance, constellations of stars were seen as familiar animal and human forms, and celestial motions were believed to influence activities on earth. Until astonomers developed more advanced notions, such metaphorical views were important in navigation, agriculture and religion—buffering the staggering incomprehensibility of the cosmos.

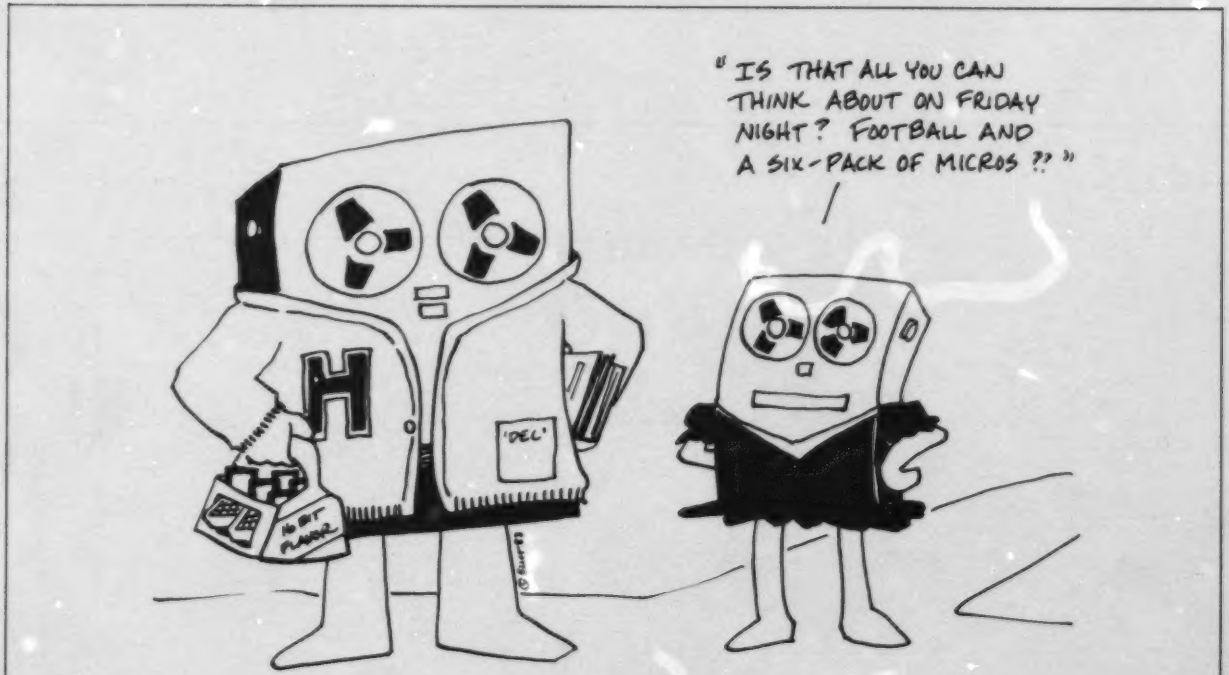
Metaphors offer a ready perspective for comprehending something new. They are particularly useful at an early stage of learning: they provide a starting place; they make connections to that which is already well-understood; they suggest possibilities for further exploration. Metaphorical approaches are especially suitable for subjects which are complex and rapidly changing—like computers.

THE COMPUTER AS PERSON

The first and most natural metaphor is the computer as person. Anthropomorphizing seems to be quite helpful when encountering a computer for the first time. (See [88].) Instructors often introduce the computer with personal expressions such as "Here he[1] is, just waiting for you to feed him some data," and beginners often wonder "What does he want now?" as if the computer had biological needs. Such an approach is a comfortable way to engage the computer and also acknowledges that the computer is, like a person, a complex system worthy of respect.

Even experienced computer scientists and technicians humanize their machines in common parlance: computers have "memory," "perform" jobs, "speak" certain languages, "don't like" mutilated punch cards, and have to be "taught" what to do. By contrast, consider how cold and impersonal the computer's image is when we restrict our language to such terms as: "input," "output," "central processing unit," "data transfer," "syntax error," etc.

Apparently, we ascribe anthropomorphic terms to computers purposefully—perhaps as a link between us and these things which are other-than-us but still like us in some ways. Robots on factory assembly lines today have "hands" and "eyes," and in the future androids may be designed with more human physical likeness in order to assure their acceptance. Microcomputers on the market now are called "personal" computers to indicate not only that they are small (and inexpensive) enough to be owned by one person but also that they are expected to be used in homes, businesses and schools—directly influencing our daily lives. It is no accident that the burgeoning computer industry advertises with culturally comfortable referents such as "Apple" (microcomputers), "Mountain" (hardware), "Dolphin" (a classroom computer-based instructional system), "Brain Food" (a courseware catalog), and "Rainbow"



THE COMPUTER AS PERSON

(a software company). Even computer software is conveniently characterized: we give programs "names"; an error is a "bug";[2] programming languages have different "features" and "reside" in some computers and not others. And, how often is the comment made that the computer "must be thinking" when there is an unusually long pause at the terminal? Computer information processing perhaps resembles our own cognitive processes more closely than any previous technology. Some people take this metaphor even further, alluding to the computer as a "brain" and attributing intelligence to it. (See THE COMPUTER AS BRAIN.)

Some instructors insist on the computer being a non-person right from the outset. "The computer is a computer. It computes, that's all." Such an attitude may unnecessarily restrict receptivity and stunt learning by nervous novices. If using a personal pronoun or even a proper name[3] helps make the computer your "friend,"[4] then chances are better for developing a deeper relationship than if you remain neutral, and the computer, neuter. As the relationship develops, you can progressively see how the computer is not like a person and outgrow the need for anthropomorphizing. Then the computer becomes your tool. (See THE COMPUTER AS TOOL.)

To be sure, there are dangers in taking the computer-as-person metaphor too literally. Making distinctions between what computers can and cannot do is important. Yet, often those distinctions are considered with regard to what humans can or cannot do. (See [6].) For instance, beginning computer users frequently say that computers can't "think," "feel," or have "consciousness"—reserving for themselves such qualities which are believed to make humans unique. Nevertheless, we must ask, "What human-like qualities should be developed in computers? And what effects will this have on education?"

Footnotes

1. The personal pronoun most often chosen for the computer seems to be "he." Perhaps this choice is just another manifestation of the general sexist bias in our society. Possibly it reflects the qualities of this predominantly male-designed machine—the epitome of hard science. In any case, who would doubt that women can understand, make good use of, or design computers?

2. The origin of the popular term "bug" is reported to be a moth which actually caused a short circuit in the old Mark I vacuum tube computer at Harvard University circa 1950. It is, of course, not strictly an anthropomorphism. However, it can be construed as being closely related to human experience. We commonly speak of having a "bug" to mean a cold or flu—something wrong with our physical health system. Usually, it is something minor and fixable. Likewise for a computer program: a bug is something causing the program not to work correctly. "Debugging" involves identifying, locating and removing bug(s) from the program.

A variety of debugging techniques abound, although they are not well articulated, much less well understood—even in the community of computer programmers. (See [83], [28] and [34] for efforts to catalog bugs.) There seems to be a rich source of intuitive knowledge here—albeit tacit and informal. Perhaps metaphors for other concepts and techniques from computing will also help us understand more about complex human processes, such as conscious thought.

The bug metaphor may also spread to other disciplines, such as psychiatry. A mental health problem can be considered a bug. Therapy, then, is debugging the mind. Sometimes one needs some help in finding such bugs, but getting rid of them must be done by the individual—just like programming. If you wrote the program, and it isn't working right, you must fix it. Ultimately you, and only you, are responsible for it.

3. A favorite name is HAL. HAL is the supercomputer portrayed in **2001: A Space Odyssey**, Stanley Kubrick's futuristic film about a voyage to Jupiter. HAL not only monitors all flight controls and life support systems, but also converses with the crew in natural English, competes in games of chess, psychoanalyzes them, and attempts to seize power to boot!

4. Titles of some recent books and articles are suggestive. (See [1], [25], [53].) Also, computer manufacturers are claiming to design more "user-friendly" systems.

THE COMPUTER AS TOOL

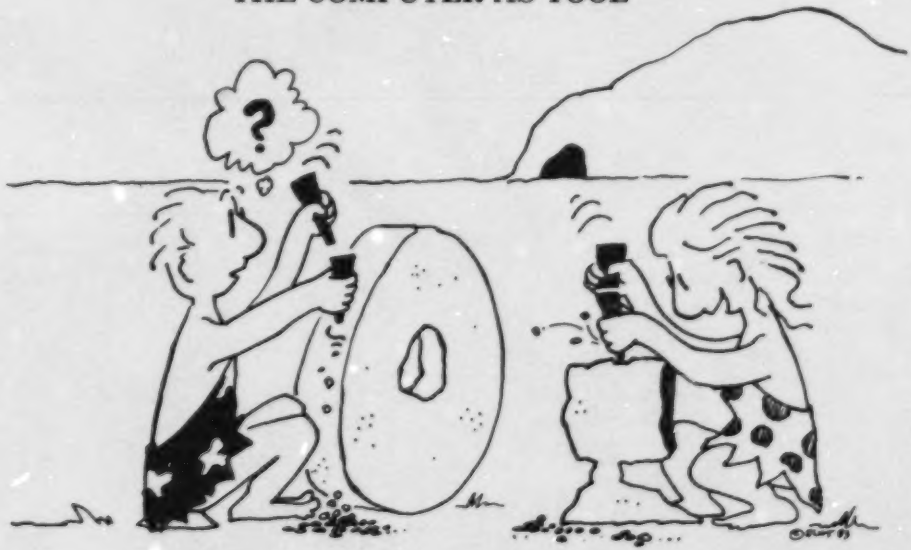
Presumably, use of tools distinguishes homo sapiens from other species, and our superior brain evolved because we continued to develop tools successfully. Now we have invented the computer—perhaps the most powerful and versatile tool humankind has ever known.

Applications of computers are already ubiquitous in most major professions of our society, including government, military, engineering, medicine, and business and industry. Large computing systems are indispensable in such crucial activities as food and materials production, transportation, communication, national defense, and scientific research. Microcomputers are being used for personal finance, record-keeping, energy conservation, security, and home entertainment. Now, the computer is impacting another important profession: education.

In education, the computer has been used as a tool in a number of areas: administration (data processing); teaching (computer-assisted instruction); diagnosis, prescription, and management of learning resources (computer-managed instruction); guidance (vocational counseling); and research (systems simulation and analysis). (See [29], [5], [32].) In teaching, the computer can be used in several different modes: tutorial, drill and practice, simulation, gaming, laboratory experimentation, problem solving, and creative/artistic projects. (See [21].)

The computer-as-tool metaphor is particularly appropriate for the independent student who uses the computer to tackle well-defined tasks.[1] For instance, in the laboratory experimentation mode, the student selects a "package" of programs, such as SPSS (Statistics Package for the Social Sciences). Typically, s/he selects certain programs, e.g., ANOVA (analysis of variance) along with desired system facilities (like a high-speed printer), applies them to data, gets results, and then departs—possibly to apply another

THE COMPUTER AS TOOL



"HEY GROG! WHEN YOU'RE DONE THERE, CAN YOU CHISEL ME A COUPLE OF DISK DRIVES?"

tool (the human brain) for further analysis. If the appropriate computer tools were used, the results should be valid; if any inappropriate tool was involved, the results may be suspect (and the student might not know it). Accordingly, the student should accept responsibility for understanding the tools s/he uses.

In the problem-solving mode, the computer is an intellectual tool, and computer programming is an essential skill. (See [8], [38].) By programming, one can take advantage of the computer's speed and accuracy to witness the consequences of one's own thinking. Here, the computer is like a mirror—reflecting back the programmer's thought processes.[2] Typically, the programmer chooses a particular programming language, selects a subset of commands and functions needed to solve a problem, embodies them in a program, and gives it to a computer to carry out. After examining the effects, s/he may change the program accordingly. Essentially, the programming language—because it is a notation executable by computer—acts as a tool for thought. (See [51].)

In the creative mode, the computer provides tools for expressing oneself artistically. It can be an instrument for making music, an electronic brush for painting, a sketch pad for drawing and manipulating pictures, and possibly, even a notebook for writing poems. (See THE COMPUTER AS PALETTE.)

Of course, the computer *is* a tool, not just a metaphor. The computer-as-tool metaphor reminds us that this Protean tool can be many, many tools. Indeed, the computer is a *super*-tool which is continually changing and evolving. Eventually, it will cause us to forge new ways of thinking and creating. (See [19].) For instance, think of the computer as a pencil. This metaphor was suggested by Seymour Papert [58] to create an image of a general-purpose tool available everywhere for anyone to use at any time for a variety of purposes (including writing). Inexpensive, portable, easy to use, and easy to understand—suppose everyone had such a personal computer. What would education be like? But, for now, the question is no longer whether or not to use the computer in education, but *how* to use this tool sensitively and intelligently. As with most technologies, the

computer is like a double-edged sword: it can be used for the betterment of humankind or to our destruction.[3]

Footnotes

1. The computer industry has already capitalized on this metaphor: Apple Computers, Inc. markets a software package called a "Tool Kit." IBM put out an advertisement referring to APL (A Programming Language) as a problem-solving tool. A popular book presenting a general method for building software systems is entitled *Software Tools* [11].

2. See also [74] p. 27 for discussion of the role of the computer as mirror in affective development.

3. Bumper sticker: "Computers are for people to use, not to use people."

THE COMPUTER AS BRAIN

Analogies are often made between computers and brains. The brain is an executive decision-maker, demanding information from bodily sensors and commanding a cadre of motor effectors, from scalp itch to toe twitch. Similarly, the computer obtains input and yields output from its terminals. Both brain and computer are control devices *par excellence.* Both have memory, process information, and can exhibit characteristics of intelligence. Examples of intelligence exhibited by computers today include: playing intellectual games such as chess; solving mathematical puzzles, algebra word problems, and geometric analogies such as those found on standard IQ tests; interpreting episodic stories; abstracting news items; analyzing outdoor scenes; and learning. (See [33], [24], [15].)

There are, of course, important differences between computers and brains. One is biochemical, whereas the other is inanimate, electronic. One has evolved by natural selection over millions of years; the other was consciously constructed (by the former) very recently. There are some things that current computers can't do very well which our human brains do perfunctorily—such as recognize faces; there are some things that computers do exceedingly well—notably, arithmetic; and there are some things that computers can't do that we can't do either—like solve unsolvable problems, or operate without a power source. But whether there are some things that our brains are capable of doing that computers can't do or won't ever be able to do remains an open and controversial question. (See [6].)

Computer-brain comparisons get a bit gray on the matter of how information is processed. No one deliberately designs computers to process information like brains, nor does anyone seriously argue that the brain works intrinsically like a computer. Although it may be helpful to refer metaphorically to the computer as a brain,[1] the analogy

"DEIRDRE – YOU DOCUMENT THE PHILOSOPHY BEHIND THE EXPERIMENT, JOHN, YOU INTERPRET THE FINDINGS. SARAH AND I WILL DISCUSS THE OPPOSING THEORIES, AND I'LL LET HAL HERE DO THE CALCULATIONS AND CHECK OUR SPELLING."

THE COMPUTER AS BRAIN 15

only holds for outward manifestations of the respective systems. One may speculate about what goes on inside the brain based on observable behavior, but it is patently difficult to determine how the brain really works.[2] Scrutiny of internal anatomical structures doesn't yield much insight into high-level functions; we can't very well take the brain apart while it is working; and even its owner can't tell you much. One way around these difficulties, however, is to build a system and see if it can be made to function effectively like a brain.

The field of Artificial Intelligence (AI) has risen to meet just such a challenge.[3] An early branch of AI called "bionics" was dedicated to simulating natural intelligence (NI).[4] More recently, a new group has chartered formal study in "cognitive science," an interdisciplinary research area which acknowledges the symbiosis of AI and NI. (See [64].) By tackling the theoretical and practical problems of AI, they hope to gain insights into human cognition; and, by studying NI they hope to discover techniques for building better AI machines.

The computer-brain metaphor has appealed to some brain theorists as well. (See [2].) Modeling individual neurons as logical elements is tempting: electrical currents flow in both brain and computer; a neuronal cell discharge appears as a single "spike" and can be conveniently represented as a binary bit—on or off. The whole brain, it might seem, is an interconnected network of such elements—a "neural net." Perhaps implementing higher-level brain functions will be possible using AI constructs such as "scripts," "frames," and other machine representations of knowledge. (See [16], [69], [4].)

There are other quite different ways of thinking about thinking which also relate to computers. For instance, consider the Left-Brain/Right-Brain dichotomy. The human brain has two hemispheres, connected by a large bundle of neural pathways called the corpus callosum. This anatomical structure has led some people to postulate two different modes of thinking: one, analytical, sequential, verbal, logical in nature (the "left" brain); the other, of a synthetic, holistic, spatial and intuitive nature (the "right" brain). (See [26].) This dichotomy has even prompted a study of the relationship of computer programming to left vs. right

hemisphere functioning. (See [72].) Perhaps computer-related activities offer hope for restoring left-right brain balance in education. (See [40].)

Lastly, a few people have ventured the idea of direct mind-to-machine hook-ups. Computers are being used in biofeedback research and therapy. (See [48], [54].) But, what if computers could interpret brain waves? Imagine the implications for education!

Footnotes

1. The metaphor is not, as some would say, that the brain is (only) a computer. On the contrary, computers have helped us realize how complex and wonder-full the brain is.

2. To begin with, ask: What is the fundamental unit of information used by the brain? (Digital computers use 0s and 1s.)

3. Research in artificial intelligence is attempting to model intelligence regardless of the form in which it occurs, according to MIT Professor Marvin Minsky, one of the pioneers in AI. (See [81].) Some people have suggested that this involves the evolution of a new species. (See [52].)

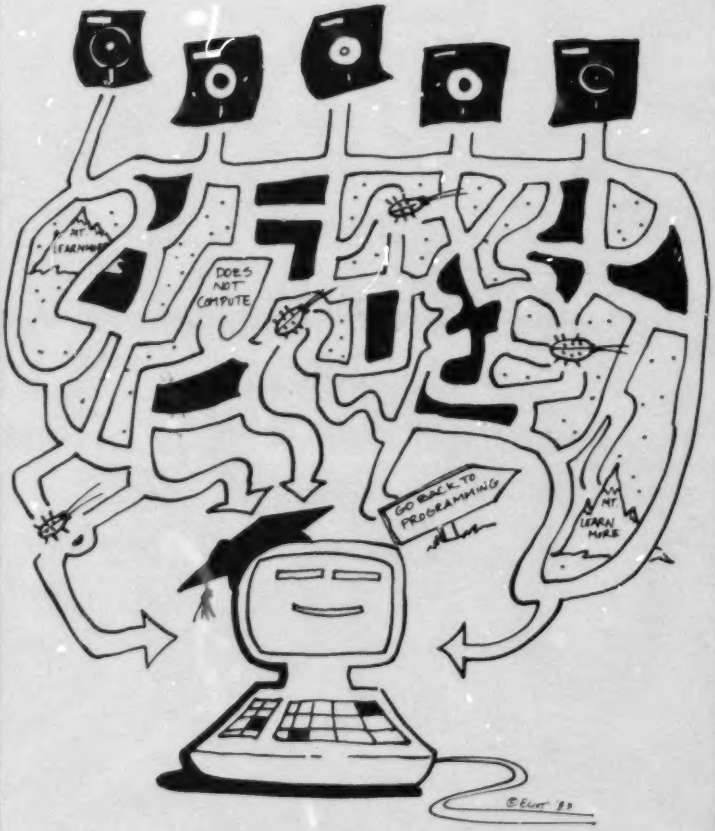
4. Is our definition of intelligence changing as machines become capable of performing more mental tasks? Note that adding up columns of numbers (now performed quickly and accurately on $6 calculators) is no longer regarded as requiring much intelligence.

THE COMPUTER AS MAP

A map shows you how to get around. A computer-managed instruction (CMI) system can do the same—in an educational setting instead of a geographical environment. (See [42].) This kind of computer-map shows the locations and connections between various centers of knowledge. For students, it tells how to get from one topic to another (usually, there are several different ways); it describes the relationship between topics (which are prerequisites for which); it indicates where you are, how far you have to go, and what resources you will need for your learning journey. For teachers, the computer provides a summary of students' educational travels. It contains valuable navigational statistics: where students have been, what routes they took, how long they stayed, and what they accomplished at each site. It can also diagnose problems encountered along the way and prescribe itineraries for future trips.[1]

At best, this metaphor is an aid for self-learning. (See [39].) Once you gain access to the computer-map, you decide where to start—it may be anywhere you like. The default starting place is an overview of the whole curriculum—like looking at peaks of mountains from an airplane, or planet earth from the moon, or our galaxy from outer space. After deciding where to begin, you travel a distance somewhere. Again, you decide in which direction to go and at what speed to proceed. At any point you may turn around and go back where you came from. Or you may pause and study details for a while. If you wish, you may skip ahead, looking for interesting landmarks. Otherwise, you keep moving at your own pace for as long as you like. You may stop at any time and pick up later where you left off—or even at some new place. The way you use the computer-map reflects your particular learning style.[2]

With this metaphor students can see learning as an active, exploring process—not unlike pioneering the frontiers



THE COMPUTER AS MAP

of western United States in the 19th century or the solar system in this century, or (soon) under the oceans. They can take increasing responsibility for their decisions and become more capable of educating themselves throughout their lifetimes. Indeed, ability to navigate a knowledge-space is a learning skill which will undoubtedly be of great value in the future. (See [30].) In a world of proliferating knowledge, the premium will be on knowing how to get around—how to get the knowledge you need when you need it—not on raw recall of far-fetched facts. And, you will need to be able to determine what knowledge is important—that is, where to spend your learning time.

Perhaps educators will begin to rely on the computer as a map. Equipped with an atlas of learning maps, a teacher can be an effective pilot, guiding students to appropriate places at appropriate times. Of course, our computer-maps will change—just as Magellan's charts gave way to modern maps—as we understand the educational topography better.

Footnotes

1. This idealistic CMI system is achievable with state-of-the-art technology but requires large effort.

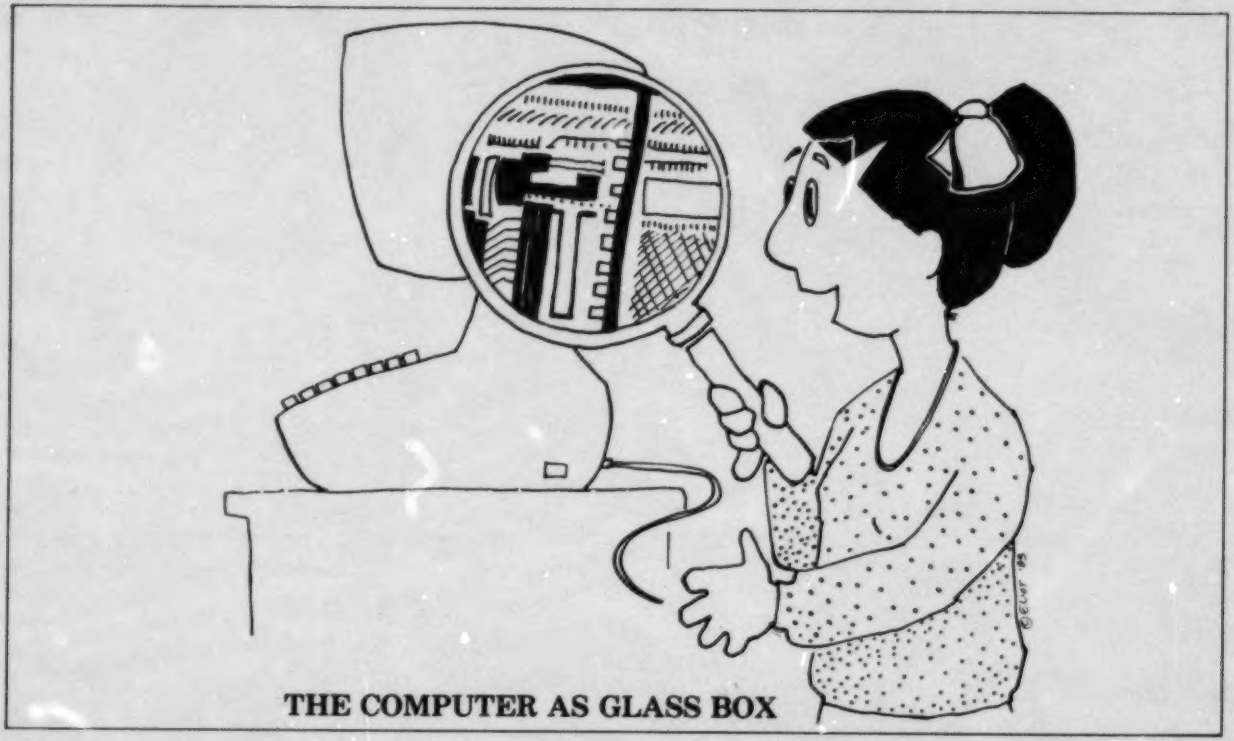
2. Some students' learning style is basically breadth-first—searching through many related topics superficially before pursuing any one in detail (much like looking over the table of contents or skimming through a book). Others proceed basically depth-first—studying one topic in great detail before pursuing related topics. Many learners combine aspects of these two styles with heuristic search techniques. (See [18].)

THE COMPUTER AS GLASS BOX

This metaphor suggests that the computer is something to be looked into. Instead of perceiving the computer as a mysterious and impenetrable "black box" and blindly accepting its pronouncements, approaching the computer as a "glass box" invites inspection and promotes understanding. Indeed, a glass box is intended to reveal rather than conceal. This approach is suitable not only for studying the inner workings of computer hardware, but also for learning computer programming techniques, for teaching selected topics in the curriculum, for exploring computer libraries, and, more generally, for enlightening social awareness of technology.

For instance, consider how the glass box approach can be used in classroom teaching. The teacher starts with a short, easily comprehensible computer program which embodies some concept or procedure. The program is written as simply and clearly as possible, making key points transparent to the student. The program is given directly to the student, who can view the program's structure as well as its behavior.[1] Then, s/he may modify the program—perhaps by changing some parameters—and experiment with it like a simulation; or s/he may attempt to generalize the program to handle related applications; or expand it into an open-ended programming project; or invent new programs inspired by the original glass box; or discuss pertinent issues with teachers and peers. (See [61].)

In curriculum, a glass box program acts as an "advance organizer." (See [41].) It prompts attention. It provokes interest. It provides an initial organization for introducing a topic. Further, the glass box approach suggests an overall methodology for computer-related curriculum development. Integrating the computer into the curriculum involves examining what is taught, when and why, with respect to how the computer can enhance the treatment. This



THE COMPUTER AS GLASS BOX

means that educators will need to reconceptualize their disciplines regularly—a practice which could spark large-scale curriculum reform. (See [84].)

The computer-glass box metaphor is particularly appropriate for students using courseware. It suggests that a good strategy for beginning lessons by computer is to look around. Browse. Peruse. Indeed, this is what students usually do when they encounter the computer for the first time: They check out what's there.[2] Typically, they get a list of file names; they find out what programs are stored where, who wrote them, and what they're like. They sample the output; they glimpse at the coding; and sometimes they even try to gain access to locked files.[3]

In general, the glass box approach assumes the philosophical position that students should develop control over their own learning. This stance is antithetical to the presumptions of conventional computer-assisted instruction (CAI), characterized by pre-programmed instructional formats and drill-and-test sequences whereby students are continually controlled by computer.

Any approach to computer literacy should elucidate the full spectrum of computer uses in education—ranging from instructional processes with a high degree of computer control (like CAI) to student-controlled computing (as in solving problems via glass box programs). If more students see the computer as a device they can control, a more technologically aware social consciousness is likely to develop.

Footnotes

1. N.B. Students would need some previous experience with an appropriate programming language, such as APL [22], BASIC [17], Logo [35], Pascal [13], or Smalltalk [36].

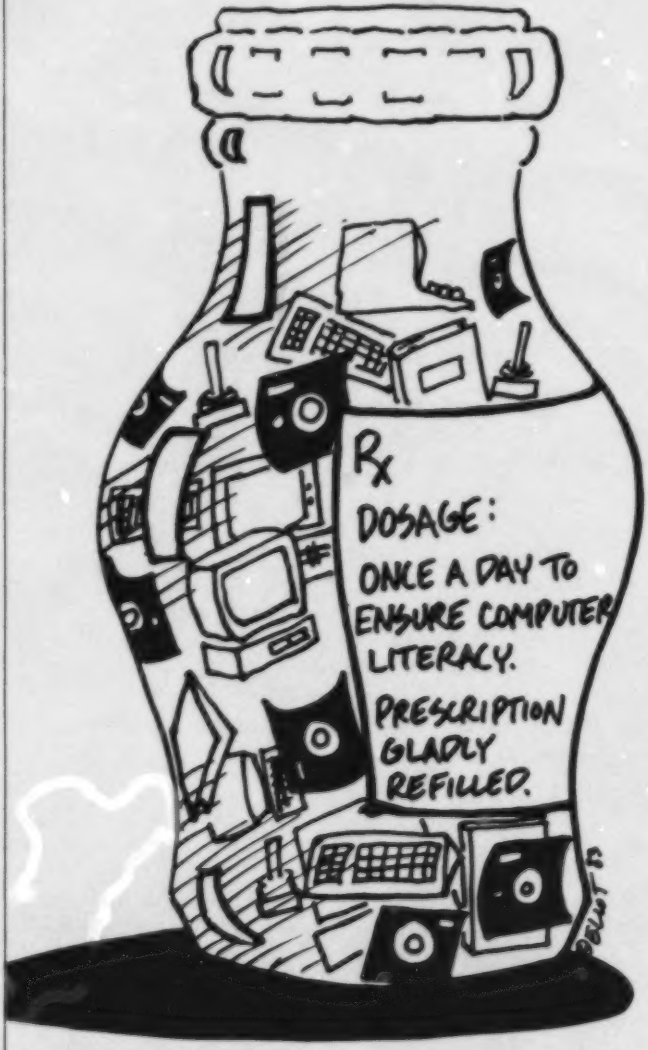
2. Such an approach is not unlike entering a new restaurant, reading the menu, looking over the pastries, taking whiffs of nearby dishes, and asking "What is the soup du jour?"

3. (Most forbidden = Most interesting)

THE COMPUTER AS VITAMIN

The idea here is that the computer provides some essential nutrients for an educational diet. Just as food vitamins are needed for normal physical growth and development, we may think of "computer vitamins" for nurturing learning. We could ask: what are the minimal daily *computer* requirements for maintaining intellectual health? In other words, what do computers provide that every student should have an opportunity to get every day? How about: a dose of excitement and fun, ample individual attention, a variety of curricular choices, plenty of encouragement and inspiration, the right amount of exercise, timely feedback, help, challenge and competition, plus chances for creative expression and time for fantasy.

How can computers provide these "vitamins"? To begin with, computers are fun—ask kids (of all ages). They offer individualized instruction, attending to your every command. You may select lessons from an appetizing menu of course-fare [*sic*]. The computer is a great motivator—it can issue pre-programmed messages of positive reinforcement as well as the implicit invitation to interact whenever you are bored or lonely. Everyone should have regular exercise, which the computer can surely provide (caution: don't overdo it). The computer also lets you know when you are right or wrong, whether it be on a test or your own programming project. It provides help (when needed) in the form of hints, review and remediation. If you want competition, try some computer games; for a challenge, set the level of difficulty higher. The computer gives students a way to study interactively yet in private (avoiding the usual embarassment of someone looking over your shoulder). There are even opportunities for fantasizing via computer.[1] And, one can be creative by designing programs to solve problems, write poetry, make music, draw pictures, etc.



THE COMPUTER AS VITAMIN

These are some computer-related activities which everyone should have a chance to do every day. (See [60].)

Footnotes

1. Witness the great popularity of "adventure games" today. What is it about these computer games that makes them so popular? See [79].

THE COMPUTER AS PALETTE

The computer provides a private studio, materials and tools for the creative artist. Consider the following sketch of how an artist might use the computer to produce a work of art. First, the artist specifies some rules for operationally defining a "painting" (a display of tiny colored dots on an electronic screen) and then enters them into a program. (It may include some random components.) The program generates a number of different paintings until it finds one which meets the specifications. If the artist likes the resulting display, s/he tells the computer to save it; otherwise, s/he requests the computer to generate some more. Alternatively, s/he may manipulate the result to her/his liking by cutting, shrinking, enlarging or replicating parts of it or by substituting different colors, superimposing images, making symmetrical reflections, or transforming it in some such way—all electronically, with no mess, no delay, and no undesirable changes in studio conditions.[1]

In this process the artist and the computer together produce artwork which may be subjected to formal analysis (either by artists or computers). For instance, the computer can process the information content of the set of paintings to search for commonalities (expressed in computational terms, like having a high percentage of red in the lower left corner). Or, after reviewing the artwork, the artist may decide to revise the program to impose different constraints. Subsequently, either computer or artist may notice a pattern in the paintings, perhaps indicating how certain aesthetic effects are evolving. This pattern could then be built into an adaptive program that attempts to converge more rapidly on particular artistic goals. Would this ensure beauty in the result? Or would it be destroyed in the process? Who can say? In any case, this is clearly a joint endeavor. And who will say wherein the creativity lies? (See [14].)

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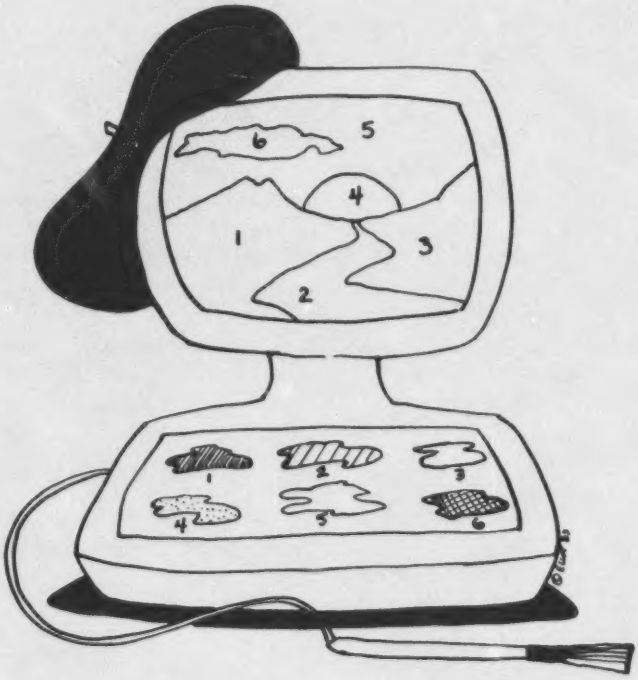


THE COMPUTER AS PALETTE

The computer-as-palette metaphor is not limited to painting. The computer can be used for producing art of other kinds including music, drawing, sculpture and cinema. (See [63], [12], [78], [77].) In music, for example, computers are being used for playing, composing, conducting, orchestrating, analyzing, printing and teaching music. The computer offers great control over sound production: one can specify precisely the envelope of a note, its timbre, pitch, duration and volume; one can transform a melody automatically by inversion, retrogradation or augmentation; one can transpose keys quickly and accurately, combine voices, introduce contrapuntal variations, etc.

Computers are opening up new possibilities in music. New kinds of sound are becoming possible.[2] Research in computer music involves studying psychoacoustics in order to know more about how music is perceived by the human ear.[3] Computers are even causing us to rethink fundamentals, such as musical notation.[4] These developments may have profound implications for education. (See [47].) Suppose, for instance, hand-held microcomputers were commonly available for learning and teaching music. How would music educators respond? (See [87].)

The computer as palette has great potential—at least for facilitating human creativity and possibly as a legitimate creator of art in its own right.[5] (See [44].) In the meantime, we need better understanding and communication in artistic domains—not only with machines, but between ourselves.[6] For instance, we don't have very good linguistic structures for talking about pictures—for describing, analyzing, and manipulating them—not to mention sequences of (moving) pictures.[7] We need to develop *graphic* languages—tools and notations for treating visual phenomena by computer.[8] Consider what effects the development of such a visual literacy would have on education and aesthetic appreciation![9]

Footnotes

1. No more worrying about paint-drying time! (Different artistic mediums require different technical knowledge.)

2. Including sounds that have never been heard before. For example, at the Stanford University Artificial Intelligence Laboratory they have simulated reverberation acoustics for sounds produced in a room of any specified size—enabling us to hear echoes without the original sound!

3. Professor Barry Vercoe at MIT's Experimental Computer Music Studio has noted that the computer's deadly accuracy may not be aesthetically pleasing and that to create what audiences consider "pleasing," the computer must be programmed to make subtle human-like mistakes in pitch and timing.

4. Now is a good time to redesign music notation. As computers become equipped with more musical capabilities, we should take the opportunity to recast and improve on conventional music notation (which already shows signs of inadequacy). The increased power and control computers afford purports to expand significantly the scope of music (and perhaps change its very nature). Surely this warrants new notation. See [85] for a discussion.

5. Perhaps art will be redefined as that which machines *can't* do.

6. Artists often are unable or unwilling to offer explanations of their work—especially "the creative process."

7. As an exercise to illustrate this point, ask someone to describe a particular scene from a TV show or an image evoked from a book. How can we get computers to understand such images in these terms?

8. Zoom, pan and windowing are just the beginning of such computer graphics tools. More sophisticated tools are being developed expressly for aesthetics. (See [46].)

9. Consider also the fanciful notion of universal aesthetic criteria, which someday we might attempt to capture with the aid of computers. Imagine a program which transforms a painting into computer-generated sound. (See [75].) Suppose, when given a Rembrandt (represented electronically), the program produces a great symphony; or, when given Beethoven's Ninth, it produces a beautiful painting. Would that program contain universal aesthetic criteria?

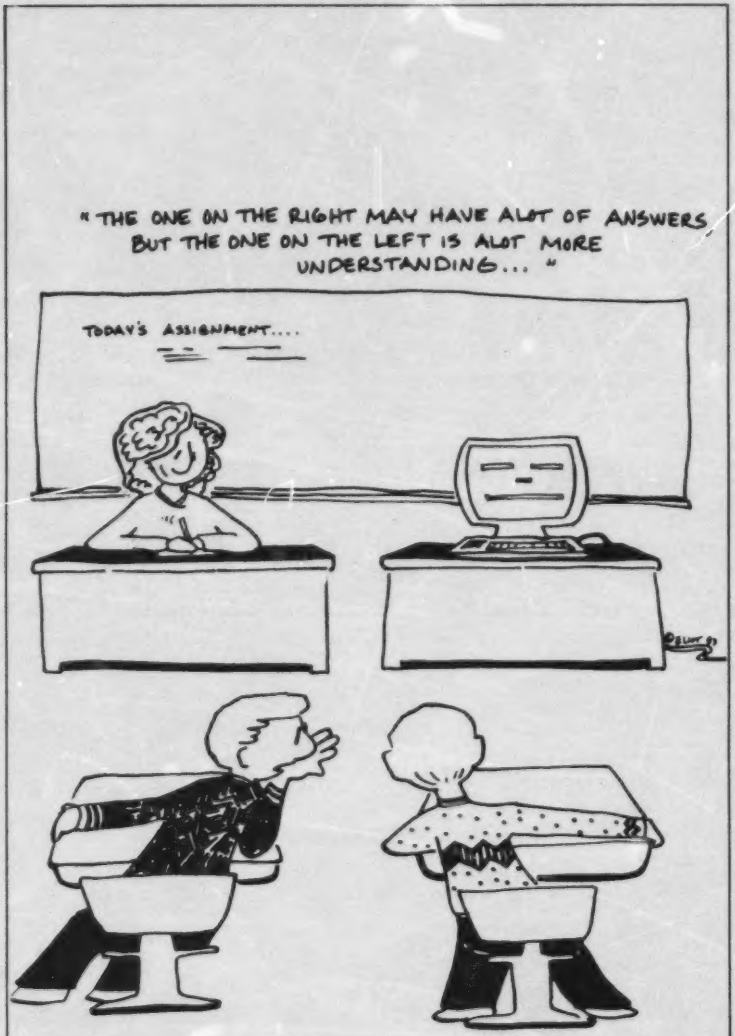
See also the tale of the "Magnificrab" (in [9]) who has magical powers of distinguishing between true and false statements in number theory by reading them as musical pieces, playing them on a flute, and determining whether they are "beautiful" or not.

THE COMPUTER AS MENTOR

Student comes home from school and sheepishly hands report card to parent. Parent grimaces. Student explains: "Well, what did you expect? I had the computer this year . . . ." Although this little joke may evoke some laughter, it provokes more serious questions about the computer as mentor: can a computer be expected to teach effectively? Would you want your child taught by a machine?

Computers have been used in teaching for more than 20 years now. Instructional applications of computers exist at all levels of education and in a wide variety of subject areas. (See [90].) Computer systems used for teaching range from large information networks to small inexpensive microcomputers. Computer corporations have invested heavily in courseware for large-scale computer-based educational systems.[1] Microcomputers now offer self-contained systems with plug-in cartridges, cassettes or discs containing lessons, games and utility programs at affordable prices. Apparently, the computer revolution is finally reaching education.[2] Educators must determine whether computers can indeed teach effectively.[3]

Can a computer possess the qualities of a good teacher?[4] Desirable qualities computers offer include endurance, objectivity, knowledge and patience. The computer doesn't get tired of teaching (not even on Friday afternoons); it treats all students the same (regardless of race, sex or religious beliefs); it holds lots of information (like a super-library);[5] and it allows students to proceed at their own pace (rather than teaching just to the middle third of the class). However, a computer has undesirable qualities as well, such as speed (it does certain things disconcertingly fast), accuracy (sometimes it is too precise), and insensitivity (it cannot respond adequately to personal needs). Indeed, there are some qualities of a good teacher which the computer does not really possess, such as spontaneity,



THE COMPUTER AS MENTOR

warmth and caring.

So, the question for educators is *what to do* with a computer-mentor in the classroom. Will teachers take advantage of the good qualities the computer affords? Or will they reject it for its bad qualities? Better yet: how will teachers complement the computer's deficiencies? How will their roles change? Suppose sorely overburdened teachers were freed from the routine and tedious aspects of teaching—conducting drills and correcting answers—by delegating those tasks to the computer. No longer expected to be the source of all knowledge, would they gratefully concentrate on other aspects of teaching such as advising, counseling, motivating and inspiring students? These are qualities which usually exalt human teaching. Will teachers exercise and develop these qualities further? With a computer-mentor available, will teachers themselves take the opportunity to learn too? Would not their joy of learning be a powerful example to show their students?

The next question brings this metaphor into sharper focus: what will educators do with "smart" computers in the classroom? The IQ of today's typical CAI system is embarrassingly low.[6] After all, it doesn't understand many things a kindergarten child does; it can't even answer questions about the material it purports to be teaching; it mostly spews out information and asks multiple choice questions. But now some "intelligent" instructional systems (IIS) are being developed.[7] (See [66], [71], [45].) In general, these systems attempt to understand the subject being taught; they require a knowledge base and programs for using that knowledge in the right situations. Besides being an expert in the subject matter, an IIS must have a model of the student being taught plus certain strategies for teaching.[8] For instance, it should be able to identify what concepts the student already knows and, perhaps more importantly, the student's misconceptions. Also, it should embody good coaching practices—deciding when to say what, which kind of hint is most appropriate, and, of course, when to shut up. (See [76].)

IISs may offer other benefits for educators too. In developing such systems, one must research a subject thoroughly and represent various kinds of knowledge in a usable form. For knowledge to be usable by a computer, it must be

represented explicitly and procedures for interaction must be well defined. In the process of building and testing an IIS, it often becomes clear where the subject material is ambiguous or why a particular pedagogical approach fails. Seeing the structure of the subject in this way can prompt productive curriculum review, reform teaching methods, and invite rethinking the design of educational systems in general. (See [56], [49], [37].)

The computer as mentor implies a new partnership in education. (See [59].) It combines use of the computer for those things it does well. Surely this metaphor has great potential meaning for educators—especially if, as it appears, computers and teachers will be working closely together in the near future.

Footnotes

1. Notably Control Data Corporation, which markets the PLATO system and has hundreds of authors developing many thousands of hours of lessons in their Courseware Acquisition Division.

2. The first wave of electronic calculators broke on the shores of education about eight years ago and even crashed into the elementary school classroom. The issue of whether or not kids should be allowed to use calculators for doing their arithmetic homework still causes quite a splash. It is a real issue, one to which there is no easy answer. It is something educators must struggle with, agonize over, and think more about until we gain a new perspective on education—much like a paradox which cannot be resolved without a larger frame of reference.

3. Is it reasonable to say that "any teacher who can be replaced by a computer should be?"

4. What *are* the qualities of a good teacher?

5. Imagine the Library of Congress at your fingertips.

6. Surely it would not pass Turing's Test (Turing's Test is a proposed method for determining when (if) a computer will be considered intelligent. It involves interrogating the computer and a human via courier. Any questions are permitted. If the interrogator cannot tell which is which, the computer would be considered intelligent. See [31]. It is hard enough to program a computer to be intelligent, much less get it to behave like a human (make mistakes, tell lies, understand jokes, etc.).

7. If we subsequently succeed in developing intelligent machines that can learn, then we will be faced with the question of how to educate them.

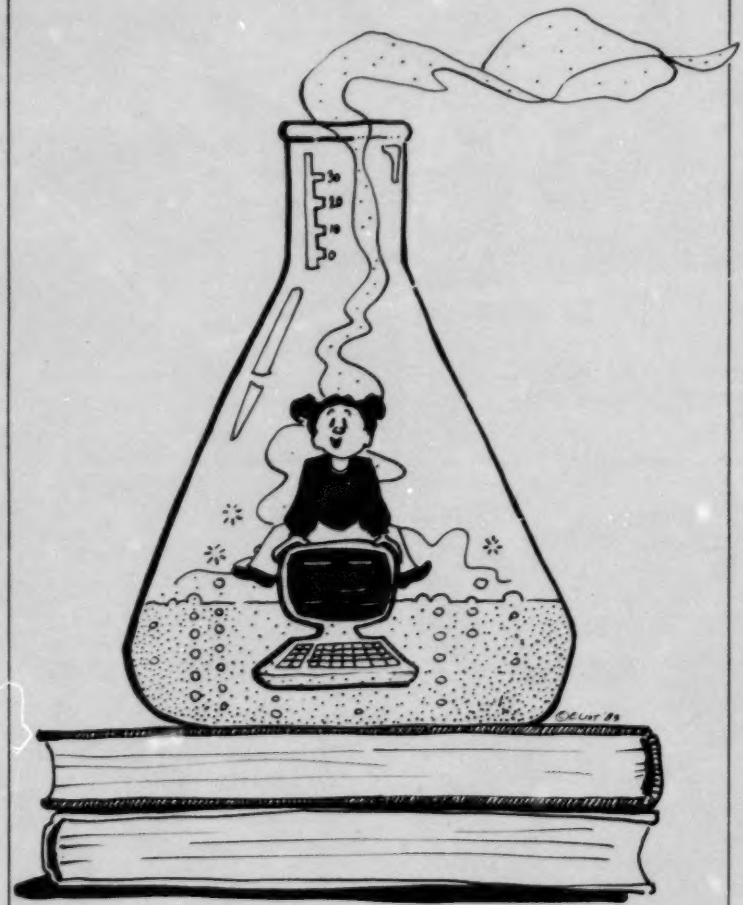
8. Not all experts are good teachers.

THE COMPUTER AS CATALYST

When you bring a computer into the classroom, things change. Some of the changes can be anticipated; some can't. Some of the changes will be desirable; some won't. But, for certain, things will never be the same again.[1]

The computer is a catalyst for revitalizing education. Hopefully, this metaphor will cause us to think not only more about computers, but also more about education. (From [7].) For instance, in using the computer to control flow of information, educators can take the opportunity to reorganize administrative procedures: determining what student performance should be monitored and when; getting standardized tests distributed and scored efficiently; disseminating timely information about school activities; scheduling new classes; matching student interests with teaching resources;[2] planning and budgeting based on a computer model of the school system;[3] generating up-to-date reports for state and federal agencies; and providing regular feedback to the local community. Further, educators can become involved in curriculum reform by considering what should be taught by computers (and what shouldn't);[4] why computers increase students' motivation to learn (See [68]); how computer-related activities can be integrated into the curriculum; how to accommodate the exponential growth of new knowledge; and, generally, how to prepare for a new "learning society" made possible by the computer.[5] (See [70], [27].)

The computer-catalyst sparks new roles for teachers. Some may assume overall supervisory responsibilities for the computer; some may want to concentrate on advising individual student programming projects; some may excel at lecturing to large assemblies about computer uses in society; some may become courseware developers; some may prefer to facilitate laboratory experimentation; and some may choose not to interact with the computer at all. There



THE COMPUTER AS CATALYST

is need for this variety of roles in using the computer in education—allowing individual teachers to do what they do best.[6]

If the computer were viewed as a catalyst, educators might be better prepared to handle rapid change. With hardly any warning, a teacher might be asked to coordinate the school's computer-related activities.[7] How can such a teacher expect to cope with the ensuing changes? There is a whole new technology to learn: new equipment, new concepts, new terminology, and new ways to teach. And there are additional responsibilities associated with daily use of the computer: its scheduling, maintenance and repair. Classroom dynamics also change. Some students become so-called "computer freaks" and indulge in an academic implosion—neglecting all their other studies in favor of intense and compulsive pursuit of everything there is to know about computers.[8] Other students who acquire advanced computer programming skills become self-aggrandizing "hot-shots," lording their expertise over others and intimidating anyone else from using the computer. A related problem occurs when students outstrip their teacher's computer competence: the teacher not only feels threatened and becomes alienated from learning about computers but also may resort to disciplinary measures to retain control and even blame the computer for causing disturbances. (The "computer as headache!") On a more positive note, the computer can trigger an explosion of curiosity in a class: some students may experience an intellectual awakening because they find something new of interest or something at which they can excel.[9]

So, educators must be ready for change. Ready for new technology. Ready for new curriculum, new questions, new ways of teaching and learning. Ready for computer clubs. Computer camps.[10] And computer crime![11] "When the computer-catalyst is involved, there are no guarantees. The computer is not a panacea for educational ills. It will not solve our problems for us; it may even exacerbate them. More likely, it will create a whole new set of problems!

Unfortunately, education seems to lack a coherent philosophy for dealing with computers. When considering using a computer, educators typically ask, "What kind of computer should we get?" without pausing to reconsider

educational objectives.[12] Some schools are now purchasing microcomputers with little idea of what to do with them, much less what they would like to do with them. This keeping-up-with-the-Jones phenomenon may turn out to be a boondoggle or a boon, depending on how successfully educators can develop a philosophical position on educational computing.[13] Instead of computer manufacturers determining what hardware, software and courseware is marketed, educators could become significantly more influential in the design process. We should ask not "What computers are available?" or "What can this or that computer do?" but "What do we *want* computers to do?" What system features, what programming language constructs, what communications interface, what human factors engineering are desirable for educational purposes? Hopefully, educators working together with computer scientists and business professionals will design appropriate computing systems, soon.

Footnotes

1. It's like changing the rules of a game—all of a sudden anything can happen. In education, the computer also raises the stakes: it makes it possible to deal with larger numbers of students, greater geographic areas, more curriculum presented in new and different ways with faster feedback, better remediation, and more enrichment—all with greater potential payoff for a computer-literate society. However, we can't expect to win simply by betting on the computer. We may even lose big by computerizing the worst of what we do now in education if we bluff that "it's got to be better because it is done by computer." Or we may get forced out early by business and industry if we continue to show disinterest and disdain.

2. Ivan Illich's "Skill Match" idea [10] could be implemented on a computer system to match a student's interests with a person who can teach those particular skills.

3. By modeling a school system—its enrollments, staff, resources, funding cycle, etc.—an administrator can specify tentative budgetary allocations for several years in advance, observe the consequences of such projections (as carried out by the computer model), and repeat the process as many times as desired with different specifications (presumably producing better projections) before making final decisions.

4. How will we decide what kernels of knowledge are most important? And, who will say what chaff gets removed?

5. The computer puts new emphasis on knowing how to get and organize knowledge rather than knowing facts *per se*. It puts a premium on learning new skills and learning how to learn. Learning is becoming a lifelong activity—a potentially joyful and rewarding activity for learners of all ages. Signs of this are apparent in the movement toward adult education and special education which recognizes society's responsibility for educating these long-ignored populations.

6. The computer helps us realize how unnecessarily restrictive some practices are in education today. For example, we seem locked into 30 students per class, 45-minute periods, identical roles for teachers, and pre-specified curriculums. See [67] for description of innovations such as "flexible scheduling," "differentiated staffing," and "microteaching." Innovations in education usually prove to be successful only when they are driven by teachers themselves. See [86].

7. The mathematics teacher is usually assumed to be the most qualified one to coordinate use of the computer. A self-fulfilling prophecy?

8. This behavior is similar to the drug/dropout syndrome. See [23] for related discussion.

9. "Novelty effect" notwithstanding, once school children get a taste of the computer-nectar, they may not be satisfied with less.

10. Computer camps have proliferated greatly in the last few years. An emerging alternative educational system? (See [43], [50].)

11. Security has always been an issue in education: measures are taken to prevent cheating on tests, changing grades, etc. The computer brings this issue into sharper focus. Kids have a similar propensity for "Sherlocking" with computers—finding out how to crack the computer's code and get into other users' files (whether to get some piece of information and leave some vernacular message or to change a record and sabotage the program). This can suggest an appealing new career in white-collar computer crime. (See [3], [20], [62].) There are big profits and low risk: if you get caught, typically you get a minimal sentence, and you may get rehired at twice your previous salary. (!)

12. The time to rethink educational objectives is *before* curriculum materials get transcribed onto computers.

13. Some choices have to be made; someone must assume responsibility for decisions regarding computers; and that means dealing with uncertainty and anguish, as well as pride and joy. See [80] for a dissertation on an existential philosophy of educational computing.

OTHER COMPUTER LITERACY METAPHORS

These are but a few of many metaphors useful for understanding computers. Hydraulic systems are often used to illustrate fundamentals of information processing, where water moving through pipes is analogous to electrons moving through logical circuitry. (See [65].) Sometimes the computer is regarded as a "pupil" which must be taught how to do everything it does.[1] And, now there is "turtle," a small computerized device which offers a wonderful metaphor for gaining computer literacy (slowly but steadily).[2] Even the automobile helps frame a controversial question: if only a small percentage of people who drive cars knows how an internal combustion engine works, why expect everyone using computers to learn computer programming?[3]

Other metaphors come readily to mind. For instance, consider the computer as a "toy." What a marvelous plaything! It provides endless hours of entertainment; it's new; it's exciting; it's fun! Or, one might think the computer is a "genie" which has just popped out of some technological bottle and can do unbelievable magic. (See [57], [55].) The computer could also be called a "crutch," doing our mental work for us.[4] Or, it is a "warehouse," storing large quantities of information in a central place, securely guarded against improper access.[5] The computer can be a convenient "scapegoat," providing an excuse for unwanted results or taking flack for unpopular policies.[6] Some people insist that the computer is (only) a computer. It does exactly what we tell it to do. It's neutral.[7] For others, it is a "Rorschach"—simulating anything you want it to be.[8] Perhaps the computer is our modern-day "idol." Are we, like Pygmalion, sculpting computers in our own image? Have we fallen in love with our creations?[9] (See [23].) Or is the computer a "crystal ball" through which we can see better scenarios for education in the future?[10].

Footnotes

1. The Dartmouth Project pioneered in introducing time-sharing computing to secondary schools in the late 1960s and characterized their approach by "the computer as pupil" [82]. Also, see [59] for a discussion of the "Computer as Learner" and see [29] for papers on the "Computer as Tutee."

2. "Turtle" is a small robot-like device which can be programmed easily to move forward or backward, turn left or right, and draw a trace of its path. Elementary school children, university mathematics majors, handicapped, and gifted students have all used turtle for actively learning "computational geometry." For further details, contact: The LOGO Project, MIT, 545 Technology Square, Cambridge, MA 01238. See also [19].

3. Should computer programming be included in an introductory computer literacy course?

4. Is the computer causing us to become lazy in our thinking? This issue was raised in the fifteenth century when the printing press made books widely available.

5. *Supposedly* secure. See [3], [20], [62] for discussions of computer crime.

6. Dr. Marcus Foster, superintendent of Oakland, California schools, was shot and killed reportedly by the S.L.A. because a computerized system was implemented for student identification. (New York Times, November 10, 1973.)

Students at Stanford University broke into the campus computer center and destroyed thousands of dollars of computer equipment with shotgun blasts. (early 1970s)

Administrators of the Springfield, Massachusetts school system defended redistricting busing routes by saying that "the computer did it" and therefore "it was the best way." (1972)

7. Is the computer a neutral technology? Is the automobile? Is nuclear power?

8. "The computer is an *anything* machine," Allan Ellis, Harvard University.

9. See [23]. This analogy suggests the larger issue of society's dependency on technology. Is it too late to "pull the plug" on computers? Can we do without cars? Electricity?

10. Thanks to Dwight W. Allen, Professor of Arts and Letters, Old Dominion University, Norfolk, VA.

CONCLUSION

This list is surely not exhaustive, for new computer metaphors are continually being fashioned. Nor were these selected as the most popular, or most effective, or in any way best for educators to use. Rather, they are simply examples of approaches which educators can use for developing computer literacy.

The brief descriptions given here do not suggest all the possibilities for using these metaphors, much less all that there is to computer literacy. Their main purpose is to get started. Metaphors may be adequate for initial understanding, but their lifespans are usually limited. Indeed, it is just as important to expose the shortcomings of a metaphor—how the computer is *not* like it and where it doesn't apply—as one pursues more technical knowledge.

Need for metaphorical approaches probably reflects the early stage of development of computer literacy in education today. Next, we must think about how to go beyond metaphor to more substantial understanding of computer science, information theory, and applications of advanced technology.

In the meantime, let us cultivate our land with computer metaphors.

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